# Atmospheric Radiative Heat Transfer in Context
Version 170827

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**Abstract:**

It is said that radiative gasses (RGs, or greenhouse gasses) trap heat radiated from the Earth's surface causing it's temperature to rise by 33 K above the theoretical temperature with no atmosphere. The word 'trap' is misleading. RGs delay the radiative transmission of heat from surface to space.

I estimate this delay and conclude that its average impact on atmospheric temperatures, the Radiative Delay Effect (RDE), is in the order of 0.14 [0.1 to 1] K. This result is then placed in the broader context of atmospheric thermodynamics where it complements recent work on the air-surface interaction. The combination leaves no significant role for carbon dioxide.

## Introduction:

The objective of this work was to quantify the rate at which radiative processes can transfer energy through the atmosphere. Specifically, it considers vertical transfer from the Earth's surface to space, which involves changes in air density, temperature, and the concentration of RGs – primarily water vapour, which condenses as the temperature drops with altitude.

The transfer rate also varies with photon wavelength. In this analysis I am ignoring the spectral aspect of the problem, which dominates most discussion of the topic. I show that to be a negligible aspect of a small effect.

Some regions of the IR energy spectrum are not strongly absorbed by RGs, so about 12% of the energy radiated from the Earth's surface passes through the atmosphere at the speed of light unimpeded. The energy involved in the remainder takes a slower journey. It is the latter flow we are concerned with here.

The atmosphere is not opaque to infrared (IR) radiation, but can be considered as translucent. It is thermoluminescent, so little of the IR photon sea that bathes our atmosphere originates from the surface. It is generated by collisions between RG molecules and other molecules.

Some of the energy of motion – kinetic energy – of the molecules is absorbed by the RG molecules, bumping them into excited energy states. This excitation energy is usually lost back to kinetic energy in a subsequent collision, since the natural lifetime of the excited states is typically far longer than the mean time between molecular collisions.

Occasionally, the excited state may decay naturally, or be stimulated by a weak collision, to produce an IR photon. Since photons travel further and faster than molecules between collisions, they can transfer energy faster than mechanical thermal conduction.

## The Process:

The procedure used is to consider a sequence of photons moving up through the atmosphere. The first, emitted near ground level, will travel an average 50 m, which is assumed to be the mean free path (mfp) of an IR photon at ground level before being absorbed by another RG molecule (1). The next photon, emitted upward from 50 m, travels a slightly greater distance, since the mfp increases as molecular density decreases with altitude.

These stages are repeated until an average photon escapes to space. Since photons travel at the speed of light their transit time can be ignored. The delay comes from the mean time between photons being emitted, per RG molecule, that move upward by at least one mfp.

Gas molecules emit photons equally in all directions. Half will move upward, and some fraction of these will reach a plane horizontal surface one mfp above the source. This fraction, a specific molecular emission rate (SMER), could be calculated from molecular physics and laboratory measurements, but fortunately we don't have to rely on totally theoretical calculations because at the Earth's surface we have direct measurements of the downward radiative flux from the atmosphere.

An estimate for the SMER can be made by first taking the surface incident radiation of 340 W/m² (2) and dividing it by the energy of an average IR photon to get the number of incident photons per second. We can assume that, on average, these are emitted from a 1 m² column of air, the height of which is approximately the mfp. From the absolute humidity we get the number of water molecules in this column, and hence the

number of photons emitted per water molecule per second that reach the ground. The simplifying assumptions made here are discussed in note (3), and allowed for in the final error range.

From radiative symmetry we can use this value in the upward sequence. At each stage, the emission rate is adjusted for the reduction in air density, temperature and composition. The delay accumulates over the stages in the upward transit to space.

The average upward energy flux through the atmosphere is around 200 W/m$^2$. This is accumulated over the total delay as increased heat in the 10 tonnes of atmosphere per m$^2$ of surface, raising its temperature. To put this into a common perspective, it is equivalent to a 200 W light bulb heating the air in a gym.

Calculations were performed using the OCM workbench (4). An annotated expansion of the code is given in (5).

**Results:**

A sample of the results is shown in Figure 1. Taking a typical surface temperature of 288 K (15 C) gives a saturation level of 10.6 g/kg and an RDE of 0.14 K. The contribution from CO2 alone is 0.001 K.
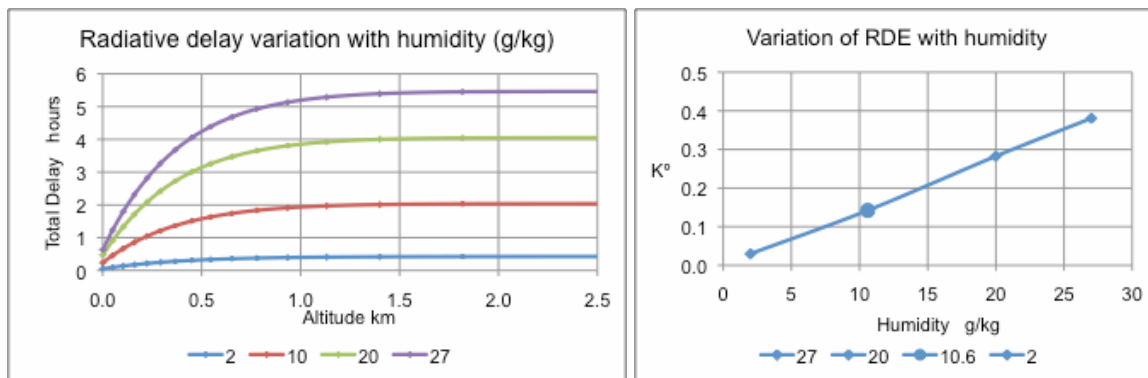


Figure 1a: IR transit delay for a condensing atmosphere and 288 K surface
1b: RDE with humidities ranging from 2 to 27 g/kg for 288 K surface

There are two distinct sources of uncertainty in these results. Wild et.al. (2) claim a 3% uncertainty for their surface radiation figures. Surface energy balance figures are disputed. I discuss some of the problems involved in (7). Here I'm taking what I see as the least controversial recent official compilation.

The main uncertainty comes from theoretical simplifications discussed in note (3). To avoid adding unnecessary complexity to the calculations and discussion I concede up to half a decimal order of magnitude, or factor of three, error from these and other approximations such as the appropriate choice of typical conditions.

**Context:**

If we assumed, as the IPCC consensus science does, that radiative energy trapped in the atmosphere dictates its temperature and that of the Earth's surface, we could scale down all their predictions by two orders of magnitude, but their view is not just an exaggeration it is fundamentally wrong.

It is based on a false assumption, made and corrected a century or so ago, that the difference between the average surface temperature of the Earth and one calculated from basic radiative physics for no atmosphere is due totally to the effect of radiative gasses trapping heat. The gap in the water vapour absorption spectrum, which allows around 12% of radiation to escape directly to space, implies a major role for CO2 which partially blocks it. Clouds are assumed to block upwelling radiation in direct proportion to coverage.

An alternative view (7) is that the thermodynamics of the Earth's atmosphere and surface are dominated, not necessarily in this order, by: two-way air-surface heat transfer; evaporative cooling and cloud formation that increases sharply at 300 K creating a thermostat effect (8); atmospheric and ocean circulation transporting fluctuations in heat and carbon dioxide on time scales that vary from hours to millennia, creating natural cyclic variation in both; cloud nucleation and other possible factors modulated by solar activity providing basic driving cycles; cloud has a strong tendency to clump or striate, allowing IR to flow around it.

The net heating effect of conductive heat transfer between the surface and lower atmosphere exists regardless of the presence of RGs, though they enhance it. This has been documented by Nikolov and Zeller (e.g. 9) and others, and is supported by the results of OCM calculations illustrated in Figure 2a where four atmospheric examples are compared: no atmosphere; an atmosphere with no radiative gasses such as pure

nitrogen; a radiative atmosphere with no evaporation and condensation cycle, such as nitrogen and CO2; and an atmosphere where water takes up heat of vaporisation at the surface and dumps it in the mid to upper troposphere where, as Figure 1a shows, the delay is minimal.
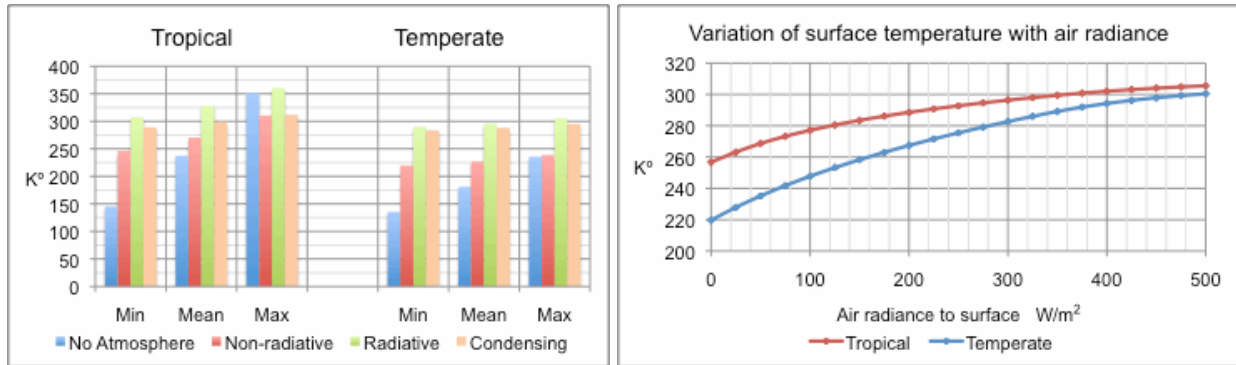


Figure 2a: Atmosphere comparisons showing daily extremes and means for surface temperatures of 299 and 288 K. 2b: Mean surface temperatures varying with incident IR radiation.

In Figure 2a, the min-max range and mean are over a daily cycle. Temperature values may be higher than they should be due to the simple nature of the model, which has a token representation of air circulation and cloud cover and ignores the localised cooling impact of storms. The condensing atmosphere assumes clouds in the choice of albedo or average reflectivity of the Earth (0.29), but doesn't model them dynamically.



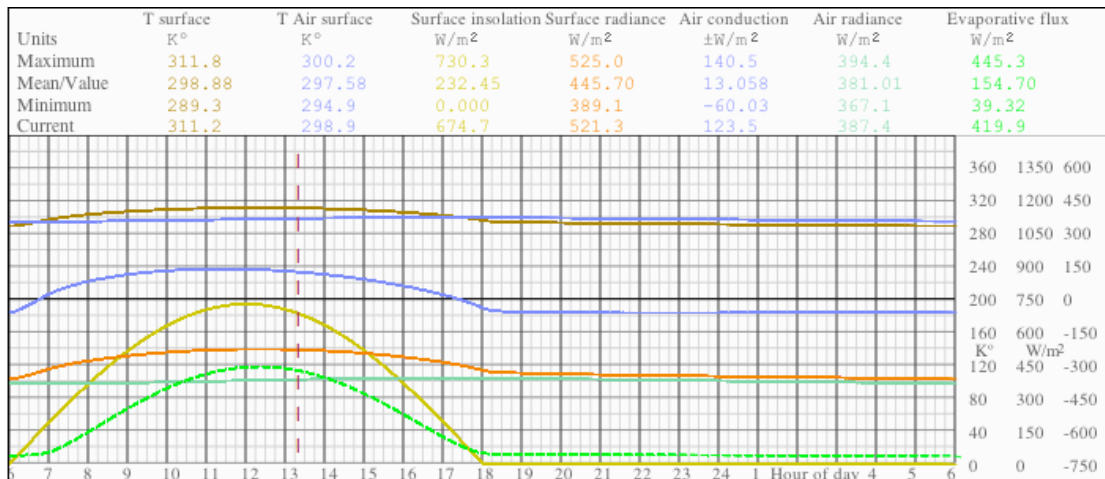| | T surface | T Air surface | Surface insolation | Surface radiance | Air conduction | Air radiance | Evaporative flux |
|---|---|---|---|---|---|---|---|
| Units | K° | K° | W/m² | W/m² | ±W/m² | W/m² | W/m² |
| Maximum | 311.8 | 300.2 | 730.3 | 525.0 | 140.5 | 394.4 | 445.3 |
| Mean/Value | 298.88 | 297.58 | 232.45 | 445.70 | 13.058 | 381.01 | 154.70 |
| Minimum | 289.3 | 294.9 | 0.000 | 389.1 | -60.03 | 367.1 | 39.32 |
| Current | 311.2 | 298.9 | 674.7 | 521.3 | 123.5 | 387.4 | 419.9 |

Figure 3: OCM plot of energy dynamics over an equatorial day for a condensing atmosphere (10).

Surface to air conduction (the dark blue line in Figure 3 plotted on the far right scale) can be seen to draw energy from the surface during the day and return it at night – as does the ground to a smaller degree even with no atmosphere.

The heat capacity of the surface is not strongly temperature dependent, so reducing its daytime temperature by 1 K removes the same amount of energy as is put back to increase it by 1 K at night. Due to the nonlinear relationship between energy radiated from the surface and temperature ($E = \varepsilon\sigma T^4$), reducing peak temperatures reduces radiated energy more than the same increase in lower temperatures increases it. The mean surface temperature increases to compensate and restore radiative balance over the daily cycle – the Atmospheric Thermal Enhancement effect or ATE.

The main impact of radiative gasses is to increase this surface coupling. As can be seen in Figures 2a and 2b, our atmosphere (Cond.) leaves little room for increasing this effect. It is almost saturated.

The ATE ranges from 61 to 107 K, not 33 K as is commonly assumed. With no evaporation cycle it is 90 to 115 K, which is in general agreement with the results of Nikolov and Zeller. This brings the impact of the delay heating from 1% of 33 K down to less than 0.5% of the total ATE.

Since both CO2 absorption and the ATE are near saturation, doubling the atmospheric concentration of CO2 would have negligible impact. It is said that such a doubling would increase the downward surface radiation ($E_{down}$ in (5)) by around 4 W/m² (e.g. 11). This, if true, would change the RDE by less than 0.01 K.

What is the sensitivityof the ATE to changes in incident radiation? From the slopes of the plots in Figure 2b at 340 W/m² we can calculate the change in the equatorial ATE from a 1 W/m² increase to be 0.06 K, and

0.12 K for a typical temperate region. Meridional atmospheric circulation, not modelled here, will bring the values closer together. This theoretical estimate agrees with a wide variety of measured values that have accumulated over the past three decades, such as the impacts of eight different natural variations in incident surface radiation analysed by Idso who found 0.1 K/(Wm$^{-2}$) (11), and others listed by Courtney (12).

Increased atmospheric CO2 has been highly beneficial to the biosphere as would a doubling. Unfortunately, that seems unlikely in the foreseeable future (13).

**Summary:**

The IPCC climate consensus view of radiative dynamics is that the sun heats the Earths's surface. The surface sheds heat through radiation and other processes. Around 88% of that radiation is trapped by RGs in the atmosphere, heating it by 33 K. They radiate much of that heat back to the surface. Surface cooling is impeded and its temperature rises. Carbon dioxide in the atmosphere reduces the gap in the water vapour absorption spectrum that allows the 12% of surface radiation to escape directly to space, so further decreasing surface heat loss. This view assumes strong positive feedbacks. It has been claimed that these could cause runaway heating.

A distinct alternate view, a total paradigm shift, is that the sun heats the surface during the day. The surface sheds heat through radiation and other processes. Around 88% of this radiation is delayed by RGs in the atmosphere, heating it by less than 1 K. Doubling CO2 in the atmosphere would increase this heating by less than 0.01 K. Meanwhile, at the surface, the intrinsic atmospheric radiation generated by molecular collisions, along with direct thermal conduction, allow the atmosphere to act as a thermal buffer reducing the daily surface temperature range and in doing so cause the surface temperature to rise by 60 K or more. This surface heating mechanism is near saturation and is in no way prone to runaway heating.

The results reported here support and quantify the latter view – one in which carbon dioxide plays an insignificant role.

**Notes and References:**

1: The choice of 50 m for surface IR mfp is a little arbitrary. It is a figure quoted before the emergence of contemporary climate science and the subsequent data corruption, but with no provenance that I've found. I've seen values between 10 and 100+ m suggested, and any value in that range would do for this analysis. Within limits, it turns out to have no impact on the delay figures since its use in calculating IR emission rates at the surface is canceled by its use in determining the delay of the stages.

For example, halving the mfp halves the height of the air column assumed to be radiating to the surface and hence the number of RG molecules emitting. This doubles the estimate of the individual molecular emission rate. Its reciprocal, emission delay, is halved. So while the number of mfp stages doubles, the delay at each stage is halved, leaving the total delay unchanged.

2: Martin Wild et.al., *A new diagram of the global energy balance*, AIP Conf. Proc. 1531, 628 (2013)

3: Assuming that the IR incident on a square meter of the Earth's surface is coming from a single column of the atmosphere above it is clearly an abstraction. The patch of ground receives IR from the whole atmosphere within visual range, but on average about half comes from within the hemisphere with a radius equal to the IR mean free path.

It is an average figure and like any average must be viewed from some larger perspective. We could base the calculation on an area of 10,000 km$^2$ so that the 10 km height of the troposphere is just a thin layer, and lateral radiation in and out of the region is a negligible edge effect. Each square meter of surface is, on average, receiving 340 W of IR. This is also the amount that is, on average, radiated from the column above it.

To keep things simple, I am ignoring the fact that in the lower troposphere approximately half the upward heat transfer is through latent heat of vaporisation and convection. Including these would reduce the role of radiation and the value of the RDE by roughly a factor of two since, as can be seen in Figure 1a, most of the delay occurs below 3km. I am also assuming water vapour saturation at all altitudes, which again overestimates the RDE.

The second law of thermodynamics and entropy require that the energy of the atmosphere be partitioned between sensible heat and gravitational potential energy. Since this point is strangely controversial, and famous physicists are quoted as ignoring the effect of gravity on atmospheric temperatures, I won't press it here. Its inclusion reduces the RDE.

I have chosen to avoid these complexities and have assigned a wide uncertainty range to the result to cover them and other factors.

4: The Open Climate Modeller (OCM) is a workbench for exploring the physics of planetary atmospheres. It follows the approach taken by Nikolov and Zeller of starting with no atmosphere and building incrementally from there. It uses HTML and Javascript, so runs in a web browser from a public server or desktop. A version of OCM, along with an equivalent spreadsheet for the delay calculations, will be made available when this article is published to allow independent analysis of the results (14).

5: Expanding the Javascript code for readability, with 0 subscripts denoting surface values:

| | | | |
|---|---|---|---|
| g | = 9.8 | $ms^{-2}$ | Gravitational force |
| cp | = 1003.5 | J/kg.K | Heat capacity of air |
| $N_A$ | = 6.022E+23 | $mol^{-1}$ | Avogadro's number |
| $k_b$ | = 1.38065E-23 | J/K | Boltzmann constant |
| mH2O | = 16 | g/mol | $H_2O$ molar mass |
| mCO2 | = 40 | g/mol | $CO_2$ molar mass |
| mAir | = 0.02896 | kg/mol | Air molar mass |
| R | = 8.31447 | J/mol.K | Universal gas constant |
| d | = 3.65E-10 | m | Effective size of air molecules |
| $airT_0$ | = 288 | K | Surface temperature |
| $airP_0$ | = 101,325 | Pa | Surface air pressure |
| L | = 5.5, 7.7, 9.8 | K/km | Atmospheric temperature lapse rates |
| h | = 0 to 20000 | m | Altitude |
| hc | = 1.9864E-25 | J.m | Planck's constant * velocity of light |
| $\lambda$ | = 1.6E-5 | m | IR wavelength |
| $mfpIR_0$ | = 50 | m | IR mean free path at surface (1) |
| airMass | = 10300 | $kg/m^2$ | Mass of total air column over 1 $m^2$ of surface |
| rCO2 | = 4E-4 | kg/kg | Atmospheric $CO_2$ level |
| $r_e$ | = 0.29 | | Relative emissivities of water vapour and $CO_2$ (15) |
| $humidity_0$ | = 0.0106 | kg/kg | Specific humidity at surface at 288 K |
| $p_{sv0}$ | = 1371 | Pa | Saturated vapour pressure at T= 288 K |
| $E_{down}$ | = 340 | $Wm^{-2}$ | IR energy flux down to surface |
| $E_{out}$ | = 200 | $Wm^{-2}$ | IR energy flux to space via atmosphere |
| $Q_{phot}$ | = 1.2415E-20 | J | Photon energy at 16 μm, hc/$\lambda$ |
| airT | = $airT_0$ - L * h / 1000 | K | Air temperature at height h |
| airP | = $airP_0$*$(1 - g*h/(cp*airT_0))^{cp*mAir/R}$ | Pa | Air pressure at height h |
| airD | = airP / (287.06 * airT) | $kg/m^3$ | Air density |
| tempR | = $(airT/airT_0)^4$ | | Modifies emissivities |
| Nrad | = (wvD + $r_e$ * CO2D) | | Density of radiative molecules |
| mfpIR | = $mfpIR_0$ * tempR * Nrad0 / Nrad | m | IR mfp at height |
| $p_{sv}$ | = from Goff and Gratch equation | Pa | Saturated vapour pressure |
| CO2D | = airD * 1000 * rCO2 | $g/m^3$ | $CO_2$ density (g by $N_A$ definition) |
| wvD | = airD * 1000 * $humidity_0$ * $p_{sv}$ / $p_{sv0}$ | $g/m^3$ | Water vapour density |
| $N_{WV}$ | = mfpIR * wvD * $N_A$ / mH2O | | Water molecules in mfp column |
| $N_{CO2}$ | = mfpIR * CO2D * $N_A$ / mCO2 | | $CO_2$ molecules in mfp column |
| $pFlux_0$ | = $E_{down}$ / $Q_{phot}$ | photons/s | Photon flux to surface |

Primary calculation

| $pFlux_0$ | $= e_{wv0} * N_{wv0} + e_{CO20} * N_{CO20}$ | photons/s | e is the SMER |
| | $= e_{wv0} * (N_{wv0} + r_e * N_{CO20})$ | | $r_e = e_{CO2}/e_{wv}$ |
| $e_{wv0}$ | $= pFlux_0 / (N_{wv0} + r_e * N_{CO20})$ | photons/molcule.s | Surface e |
| $e_{wv}$ | $= pFlux_0 * tempR / (N_{wv} + r_e * N_{CO2})$ | | N, T and e varying with height |
| $tDelay_h$ | $= 1 / e_{wv}$ | seconds | Specific emission delay per stage |
| | $= (N_{wv} + r_e * N_{CO2}) / (pFlux_0 * tempR)$ | | |
| $tDelay_{tot}$ | $= \sum^h tDelay_h$ | seconds | Delay summed over stages |
| $Q_{delay}$ | $= E_{out} * tDelay_{tot}$ | J | Energy delayed |
| $\Delta T_{atm}$ | $= Q_{delay} / (cp * airMass)$ | K | Atmospheric temperature increase |

6: Engineering Toolbox, *Evaporation from water surfaces*.

7: This view is the current personal perspective of the author. It is not meant to represent any form of collectivist or consensus view, though I am indebted to the many individuals who have informed it.

8: Dai Davies, *Energy and Atmosphere*, brindabella.id.au/climarc/  Energy&Atmosphere.pdf

9: Ned Nikolov, Karl Zeller, *Unified Theory of Climate. Expanding the Concept of Atmospheric Greenhouse Effect Using Thermodynamic Principles: Implications for Predicting Future Climate Change*, http://www.wcrp-climate.org/conference2011/posters/C7/C7_Nikolov_M15A.pdf

10: This is an OCM time display. The underlying model is a rough first approximation of local conditions and is not fine-tuned to any particular context.

11: Sherwood B. Idso, 1998, CO2-induced global warming: a skeptic's view of potential climate change, Climate Research, Vol. 10: 69–82

12: Richard S. Courtney: https://wattsupwiththat.com/2017/04/17/the-good-the-bad-and-the-null-hypothesis/#comment-2478304

13: Dai Davies, *The IPCC and the Carbon Cycle – Fact or Fantasy?*, brindabella.id.au/climarc/dai/IPCC-CO2/IPCC-CO2.pdf  or html

14: RadiativeDelay.xlsx accompanying this document provides an alternative to OCM.

15: Paul D. Ronney, http://ronney.usc.edu/AME517F09/PlanckMeanAndLeckner.xls. See (14) for details.

16: Leckner B., *Spectral and total emissivity of H2O and CO2*, Combustion and Flame, 19, 33, 1972